ATTACHMENT S3C1: GROUNDWATER INTERIM MEASURE DESCRIPTIONS

1.0 PLANT 2 GROUNDWATER INTERIM MEASURES DESCRIPTIONS

Areas of impacted groundwater in Boeing Plant 2 (Plant 2) have undergone a variety of Interim Measures (IMs), generally designed to contain or reduce contaminant mass within the impacted area. IMs are not specifically designed to achieve regulatory cleanup levels such as the Target Media Cleanup Levels (TMCLs) for Plant 2; however, some of the technologies used to perform the groundwater IMs can achieve TMCLs. The general locations where Plant 2 groundwater IMs were performed are shown in Figure 3-5 in Volume X. Descriptions of groundwater IMs performed from 1993 through 2012 are presented in the following sections.

1.1 2-66 Sheetpile

Subsurface assessments performed at Plant 2 during the early 1990s detected elevated concentrations of chlorinated volatile organic compounds (cVOCs) associated with Building 2-10 north and south degreasers and a former aboveground trichloroethene (TCE) tank southwest of Building 2-66.

Buildings 2-10 and 2-66 historically contained parts machining and fabrication operations and TCE degreasers to remove oil and grease from metal parts. The degreasers, aboveground TCE tank, and associated piping were decommissioned and removed.

Sheetpile stabilization was selected as an IM to contain and isolate soil and groundwater containing elevated cVOCs associated with former solvent degreasing operations or leakage from the aboveground TCE tank.

The alignments of the sheetpile containment structures were designed to contain the majority of the extent of cVOCs in subsurface soil and groundwater within the physical and operational constraints of the facility at the time the sheetpile structure was installed. All three sheetpile containment structures are “hanging sheetpiles” because they are not driven into an underlying low-permeability formation. Installation of the containment structures began in November 1993 and was completed in May 1994.

The sheetpile structures consist of interlocking steel sheets (Waterloo Barrier®) with a thickness of 0.295 inches. The sheets were driven into the subsurface using a vibratory hammer. The individual sheetpiles at the Building 2-66 containment structure extend to a general depth of approximately 50 feet below ground surface (bgs). In a few isolated locations the sheetpiles could not be advanced to the full 50 foot depth due to subsurface obstructions. Most of the sheets are at least 45 feet deep with only one sheet being terminated at 39 feet bgs in the northwest corner of the structure. The sheetpiles have interlocking joints that contain a cavity, which were filled with an impermeable sealant to prevent groundwater migration through the sheetpile joint (Weston 2001).

Evaluations of groundwater quality in the area downgradient of the 2-66 Sheetpile indicate that samples from wells had non-detections for TCE or had TCE concentrations that remained approximately the same from 1995 to 2001 (Weston 2001). The results of studies performed at the 2-66 Sheetpile structure indicate that elevated cVOC concentrations in groundwater appear to be contained within the containment structure and the containment structure is performing as intended. Impacted groundwater inside of the containment structure has limited mixing (driven by diffusion and tidal fluctuations) with groundwater outside of the sheetpile.

1.2 Diesel Recovery Area

During a groundwater investigation performed in 1992 approximately three feet of floating product, identified as diesel fuel, was found in monitoring wells near the southwest corner of Building 2-66.

In 1995 The Boeing Company (Boeing) installed an extraction well and product recovery system in the southwest corner of Building 2-66 as an IM. The system consisted of an air-operated product recovery pump, a 550-gallon double containment product recovery tank, and associated piping, instrumentation, and alarm systems (Weston 2000).

The product recovery system was installed in January and February 1995 and was operated for 5.5 years until operation was terminated on October 17, 2000. Over the 5.5 years of operation, approximately 1,300 gallons of floating product was recovered by the system. Operation of the system was terminated after Boeing determined that there was no longer enough recoverable floating product to warrant continued operation of the product recovery system.

The product recovery system was dismantled in November 2000 prior to the planned demolition of Building 2-66. The product pump and electronic control systems were removed and any part of the system that was potentially in contact with product was decontaminated. The 4-inch product extraction well was left in place in a locked steel protective riser and was protected from damage during Building 2-66 demolition for potential future use if warranted.

The product extraction well was decommissioned in June 2010 to allow excavation and installation of a duct bank. The well was decommissioned by pressure grouting in place following Washington State Department of Ecology (Ecology) well decommissioning requirements under Washington Administrative Code (WAC) 173-160-460(2).

1.3 2 66 Sheetpile Density-Driven Convection

As noted in Section 1.1, the sheetpile barrier IM at Building 2-66 successfully fulfilled its objective of containing the majority of the contaminant mass in soil and groundwater between the source areas and the Duwamish Waterway. However, this type of containment IM action does not facilitate regulatory closure of Plant 2 and requires maintenance and monitoring for an indefinite length of time, and that length of time could exceed the functional lifespan of the sheetpiles themselves.

The primary objective of the 2-66 Sheetpile Density-Driven Convection (DDC) IM was to perform mass removal and subsequent capture and destruction of volatile constituents of concern (COCs) in vadose zone soil and groundwater inside the sheetpile containment structure near Building 2-66.

A second objective of the IM was to provide specific information on the use of the remedial technology inside hanging sheetpile containment structures. The use of the DDC technology inside the 2-66 Sheetpile containment structure was an innovative approach and uncertainties existed regarding how operation of the system would affect piezometric conditions, which could induce unwanted contaminant migration outside of the sheetpile.

DDC is a form of in situ (in well) air stripping and incorporates and integrates soil vapor extraction (SVE) and air stripping components. The operating principle is the same as in an airlift pump except that the pumped water was not allowed to reach the surface. Rather than reaching the surface and exiting the well at the wellhead, the water exfiltrated from an upper well screen into an infiltration gallery constructed in the vadose zone and re-entered the well through an inlet screen near the bottom of the casing. This established a convection cell in three dimensions, the size of the cell being determined by the spacing between the inlet screen and exfiltration screen, the difference in vertical and horizontal hydraulic conductivity of the aquifer, and the rate of air flow.

The airflow used to move water up the well casing also stripped volatile compounds from the water entering the well. A vacuum applied to the wellhead captured vapor-phase contaminants stripped from the water. Volatile contaminants in the vadose zone were captured through the vacuum radius of influence created by the vacuum at the wellhead and were drawn from the vadose zone through the unsaturated portion of the exfiltration well screen. The SVE component also captured vapors liberated from groundwater as the exfiltrated water migrated downward to the water table.

The extracted contaminants were entrained in the SVE vapor effluent stream and drawn into the vapor treatment system. While in DDC mode, the vapor treatment system was operated as a closed loop system without atmospheric discharge. The effluent air stream was treated to remove contaminants prior to reinjection for the in-well stripping. Vapor treatment included a moisture knockout to reduce the water content of the vapor effluent stream and vapor-phase carbon (VPC) as the primary contaminant treatment. Additional air effluent treatment was provided by vapor-phase zeolite (VPZ), which is potassium permanganate infused granular zeolite, primarily to remove vinyl chloride (VC) and polish the air stream prior to re-injection. The contaminants absorbed by the effluent vapor treatment system (VPC and VPZ) were destroyed at a carbon regeneration facility.

DDC system installation began in late 2003 and was completed in early 2004. Details of the installation are reported in Construction Report for Interim Measures Density-Driven Convection System near Former Building 2-66, dated November 29, 2004 (EPI 2004). The DDC system consisted of two DDC wells installed within the 2-66 Sheetpile structure and 11 new monitoring wells/piezometers installed inside and outside of the sheetpile structure. Soil and groundwater were sampled and analyzed as part of system installation and those results are also presented in the Construction Report.

The DDC system began operation on March 23, 2004 and operation was terminated per United States Environmental Protection Agency (USEPA) approval on August 24, 2007. During system operation, the DDC monitoring wells were sampled 16 times at quarterly intervals.

Soil sampling inside the 2-66 Sheetpile was performed in September 2006 to provide an updated total volatile organic compound (VOC) mass within the sheetpile in both soil and groundwater. A report titled Interim Measure Evaluation and Completion Report at the Building 2-66 Sheetpile (EPI 2007), submitted to USEPA in mid-May 2007, summarized this work and the overall results of DDC system performance.

Data evaluations indicated total VOC mass reductions of approximately 98 percent for groundwater and soil combined occurred in the 2-66 Sheetpile over the period from May 2003 to September 2006. The May 2003 estimate of total VOC mass in soil was 8,012 pounds and the September 2006 estimate of total VOC mass in soil was 174 pounds. The May 2003 estimate of total VOC mass in groundwater was 716 pounds and the September 2006 estimate of total VOC mass in groundwater was 21 pounds.

Boeing proposed that the reduced VOC mass and concentrations left inside the sheetpile would be more efficiently remediated by a method other than continued operation of the two DDC wells. Subsequently, in an August 14, 2007 letter from the USEPA to Boeing, the USEPA approved termination of DDC System operation. Boeing terminated DDC System operation on August 24, 2007.

1.4 OA-12 Enhanced Reductive Dechlorination

The OA-12 Enhanced Reductive Dechlorination (ERD) IM was a pilot-scale IM project performed on the high-concentration portion of the cVOC plume present beneath former Building 2-63, which was identified as Resource Conservation and Recovery Act (RCRA) unit OA-12. Data indicated that the plume likely originated at former Building 2-62 and extended beneath Buildings 2-63 and 2-65, and into the 2-66 Area.

ERD is a microbiological remedial process that combines the application of microbiology, chemistry, hydrogeology, and engineering to affect an enhanced microbial degradation of targeted compounds. ERD stimulates the anaerobic process through which certain capable bacteria (halorespirers) degrade cVOCs by successively removing chlorine atoms. In this redox reaction hydrogen is the electron donor (becomes oxidized) and the cVOC is the electron acceptor (becomes reduced). Tetrachloroethene (PCE) is dechlorinated to TCE, which is dechlorinated to cis-1,2 dichloroethene (cDCE), which is dechlorinated to VC, which is finally dechlorinated to ethene and ethane. Each dechlorination step in the process requires stronger reducing conditions to complete than its predecessor.

For ERD to be successful the correct bacteria (halorespirers) must be present in sufficient quantities; in addition, reducing conditions (hydrogen present, oxygen absent, low redox potential) must exist, a food source (organic contaminant in this case) must be available, and other minor nutrients (phosphorous, etc.) for biological growth must be present. By injecting the proper nutrients, reducing conditions in the subsurface can be enhanced to the point where the dechlorination process begins to accelerate.

EPI installed a line of three A- and B-Level pairs of injection wells, aligned perpendicular to the groundwater flow direction, across the centerline of the OA-12 plume with a spacing of approximately 50 feet between the injection well pairs. In addition, paired monitoring wells and a single monitoring well were installed parallel with the plume axis and in line with the center injection well and two existing monitoring wells. The monitoring wells were located at distances approximately 50, 100, 150, and 250 feet downgradient of the line of injection wells. Existing monitoring wells were also incorporated into the OA-12 IM monitoring well network. The relatively close spacing of monitoring wells to the injection wells was intended to provide quick feedback on the progress of ERD remediation.

A nutrient substrate consisting of a carbohydrate solution of reclaimed waste beverages was initially pumped into the six new injection wells to start the ERD process. The target sugar concentration for the nutrient substrate was 6 percent but varied from 3.5 percent to 10.5 percent because the nutrient solution, being a recycled feedstock, was delivered to the facility at inconsistent concentrations.

The first nutrient substrate injection was performed during the summer of 2008. Because most of the cVOC contamination at OA-12 is in the A-Level and because the B-Level is naturally more anaerobic than the A-Level at Plant 2, the injections were designed to add more solution and sugar into the A-Level. Approximately 21,000 gallons of nutrient substrate solution (average sugar content of 8.1 percent and equaling about 14,500 pounds of sugar) were injected into the A-Level of the aquifer and 15,000 gallons of nutrient substrate solution (average sugar content of 4.5 percent and equaling about 5,600 pounds of sugar) were injected into the B-Level. Details of the nutrient substrate injection were presented in the Other Area 12 Interim Measure – First Semiannual Report (EPI 2009a).

A second nutrient substrate injection was performed in the spring of 2010. The second nutrient substrate injection consisted of a dissolved sugar and sodium bicarbonate solution and is described in an approved Work Plan Addendum (EPI 2010a). Sugar was used as the nutrient substrate for the second injection to remedy transient low pH issues that were encountered with the original reclaimed waste beverage substrate. Approximately 14,700 gallons of nutrient substrate solution containing 7,400 pounds of sugar was injected into the A-Level of the aquifer and approximately 7,400 gallons of nutrient substrate solution containing 3,200 pounds of sugar was injected into the B-Level. The second nutrient substrate injection was documented in the Other Area 12 Interim Measure – Fourth Semiannual Report (EPI 2010c).

The primary objective of the IM was to destroy contaminant mass in the subsurface. To measure the success of this objective, a groundwater sampling and analysis program was conducted to quantify baseline and post-treatment contaminant concentrations in the subsurface. A secondary objective of the IM was to collect data to evaluate the potential application of the ERD process at other cVOC contaminated sites at Plant 2. Bimonthly performance monitoring was initiated in October 2008 to assess geochemical responses in the subsurface and remediation progress by following concentration trends of COCs and ERD-related parameters. The performance monitoring schedule was changed to quarterly following the October 2009 sampling.

Data presented in OA-12 ERD IM reports demonstrate establishment of the geochemically reducing subsurface conditions that are necessary for ERD. Monitoring data also demonstrate a measurable increase in dehalogenating bacteria census at the injection wells and downgradient wells sampled for bacterial census. A review of total organic carbon (TOC) and field data indicates that the nutrient substrate injection, and resulting reducing geochemical conditions, appeared to have reached the farthest downgradient monitoring well, which is 250 feet downgradient from the injection line.

Analytical data indicate a decrease in cVOC concentrations in samples from two A-Level injection wells and downgradient A-Level monitoring wells up to 150 feet downgradient of the injection wells. These data demonstrate that the nutrient substrate injection successfully initiated and sustained ERD in the A-Level of the aquifer at injection wells and in wells up to 150 feet downgradient of the injection wells.

The B-Level of the shallow aquifer at Plant 2 is generally more naturally geochemically reducing than the A-Level because it is deeper and is not in contact with oxygen in vadose zone pore spaces. Data from OA-12 IM sampling Indicate that nutrient substrate injection resulted in similar reducing geochemical characteristics in both A- and B-Levels. This result was achieved with the A-Level receiving approximately 2.6 times the nutrient substrate loading (total mass of sugar) relative to the total sugar injected into B-Level wells during the initial nutrient substrate injection. Dissolved methane gas concentrations for both levels of the aquifer indicate similar reducing geochemical conditions at locations up to 150 feet downgradient of the injection wells. This finding indicates that geochemically reducing conditions can be achieved as successfully in the A-Level of the aquifer as the B-Level if the A-Level is supplied with sufficient nutrient substrate.

Data trends indicate that nutrient substrate injection at OA-12 as a pilot-scale test has achieved the reducing geochemical conditions necessary for ERD in both the A- and B-Levels of the aquifer, and the ERD process has measurably decreased cVOC concentrations in samples from most of the wells in the OA-12 ERD IM monitoring network.

Current Plant 2 demolition and construction activities prevent access to the OA-12 ERD IM monitoring network. Further groundwater monitoring and reporting for this IM were discontinued as approved by the USEPA in an e-mail communication dated June 2, 2011 (USEPA 2011). Groundwater remediation through the ERD process will continue as long as sufficiently reducing geochemical conditions are present in the aquifer.

Additional soil and groundwater remedies will be performed as required to meet cleanup goals during Corrective Measures Implementation (CMI).

1.5 2-66 Sheetpile Enhanced Reductive Dechlorination

Based on the successful removal and destruction of the bulk of the VOC contaminant mass, Boeing proposed further groundwater remediation using an alternative technology. Boeing selected in situ ERD to dechlorinate and destroy the remaining cVOC mass in groundwater within the 2-66 Sheetpile.

The ERD IM was proposed and described in a work plan titled Interim Measure Work Plan for 2-66 Sheetpile (EPI 2008a). The USEPA approved the work plan in a letter to Boeing dated August 11, 2008 (USEPA 2008).

As discussed in the previous section, ERD is an in situ chemical application that temporarily modifies groundwater geochemistry to promote the growth of certain bacteria that are effective in the reductive dechlorination of cVOCs. Under appropriate geochemical conditions certain anaerobic bacteria can metabolize cVOCs by successively removing chlorine atoms from the ethene backbone until only ethene or ethane gas remains.

Implementation of the 2-66 ERD IM was described and reported in the 2-66 Enhanced Reductive Dechlorination Interim Measure – First Semiannual Report (EPI 2009b).

Baseline groundwater sampling was performed at 15 monitoring wells inside the 2-66 Sheetpile on August 27 and September 2 and 3, 2008. Baseline monitoring was conducted to provide initial COC concentrations and subsurface geochemical conditions prior to implementing ERD.

The initial substrate injections took place from October 7 to 16, 2008. A nutrient substrate solution of approximately 6 percent sugar and 2,400 milligrams per liter (mg/L) of sodium bicarbonate buffer in potable water was injected by direct-push technology (DPT) into a grid of 26 locations spread uniformly inside of the 2-66 Sheetpile. Approximately 9,500 pounds of sugar was injected throughout the 2-66 Sheetpile: 7,520 pounds (13,400 gallons of substrate) were injected into the A-Level and 1,980 pounds (3,500 gallons of substrate) were injected into the B-Level. The B-Level of the aquifer is naturally more anaerobic at Plant 2 so a lesser volume of nutrient substrate was injected to promote ERD in that level.

A second injection of nutrient substrate was conducted from May 4 through May 13, 2010. The second injection was similar to the first and was based on the need to replenish nutrient substrate concentrations to maintain conditions favorable for ERD.

The first nutrient substrate injection initiated the ERD process, which, in turn, stimulated microorganisms in the subsurface to reductively dechlorinate and destroy chlorinated VOCs. The second nutrient substrate injection provided the necessary nutrient load to groundwater to continue the ERD process. As a result, cVOC concentrations for samples from 15 of the 19 monitoring wells sampled for the 2-66 ERD IM have decreased and/or shifted to less-chlorinated forms. Samples from eight of the 19 wells indicated that cVOC concentrations were decreased by 90 percent or greater.

1.6 OA 9 Enhanced Aerobic Degradation

The OA 9 Enhanced Aerobic Degradation (EAD) IM was performed at the OA 9 RCRA unit, which consists of three former underground storage tanks (USTs) identified as PL-16, PL-17, and PL-18. Solid Waste Management Unit (SWMU) 2-78.6 is a nearby former oil-water separator. When the three USTs and oil-water separator were removed from the OA 9 IM area, some contaminated soil was inaccessible and left in place due to numerous subsurface utilities.

As a result, impacted soil remained in discrete areas next to and within underground utility corridors, which made the subsurface distribution of contaminant sources at OA 9 very heterogeneous.

Based on the 2-60s Area Data Gap Investigation (DGI) Report (EPI and Golder 2007), COCs for vadose zone soil and groundwater at OA 9 were gasoline-range petroleum hydrocarbons (GRPH) and the VOCs benzene and ethylbenzene. Figures showing the locations of the soil detections and groundwater plumes are presented in the OA 9 IM Work Plan (EPI 2008b).

Bioventing was selected as the IM soil treatment technology for vadose soil and EAD was selected as the IM groundwater treatment technology. These two technologies complement each other and were implemented together at OA 9 to introduce oxygen into the subsurface soil and groundwater. The increased available oxygen was intended to enhance aerobic bacteria populations, which destroy contaminant hydrocarbons and non-chlorinated VOCs through aerobic metabolism of the organic contaminant molecules.

Bioventing is an in-situ soil remedial technology that introduces oxygen in air into the open pore spaces of vadose zone soil by using a blower to inject air at relatively low-flow rates into the soil through a series of injection wells. The oxygen introduced into the soil stimulates indigenous aerobic microorganisms to metabolize and destroy organic compounds adsorbed to vadose zone soil.

EAD is an in-situ groundwater remedial technology that introduces chemically bound oxygen into groundwater, which stimulates the growth of indigenous microorganisms. The enhanced microbial populations metabolize and destroy GRPH, benzene, and ethylbenzene in groundwater. The oxygen-release compound used at OA 9 is a proprietary product with the trade name EHC-O™, which is produced by Adventus Americas, Inc. Detailed descriptions of these remedial technologies and their applicability and limitations are presented in the OA 9 IM Work Plan (EPI 2008b).

Prior to this IM, remedial work at OA 9 included excavation and removal of impacted vadose zone soil; however, buildings and extensive subsurface utilities in the area prevented the removal of all the impacted soil. Bioventing was implemented to remediate these remaining pockets of impacted vadose soil and augment concurrent work to remediate the associated groundwater plume.

In September 2008, six bioventing wells were installed to facilitate in situ remediation of impacted vadose zone soil. During October and November, pipe trenches were dug and 2-inch diameter polyvinyl chloride (PVC) pipe was installed to provide a supply of pressurized air to the six new bioventing wells and three existing wells modified to serve as bioventing wells. A blower, trailer, pipe manifold, and electrical power were then installed and connected to supply air to the bioventing wells. Respirometry testing was performed quarterly to monitor the status of the bioventing system.

During October and November 2008, a solution of 5,000 pounds of EHC-O™ and potable water was injected into the groundwater in a grid of 20 points by DPT. The injections were made over the depth interval from 10 to 30 feet bgs. Details of the injection process are presented in the Other Area 9 IM – First Semiannual Report (EPI 2009c). Groundwater was monitored quarterly to assess the progress of groundwater remediation.

Operation of the OA 9 IM was terminated in June 2010. Based on evaluations of groundwater monitoring data, gasoline range petroleum hydrocarbons (GRPH), diesel range petroleum hydrocarbons (DRPH), and benzene, toluene, ethylbenzene, total xylenes (BTEX) concentrations in groundwater performance samples have declined in five of six wells in the OA 9 IM monitoring well network after 1.5 years of remedial treatment. Samples from two of the OA

9 IM monitoring wells exhibited declining concentrations of COCs; however, GRPH and benzene remained at concentrations greater than Plant 2 TMCLs in samples from two of the six wells in the OA 9 IM monitoring well network.

Oxygen concentration curves generated from respirometry testing data indicated that oxygen consumption rates in vadose zone soils declined during the 1.5 years of IM operation. Oxygen uptake rates declined to the point of being too small to measure at several measurement locations. The decrease in oxygen consumption rates indicates that contaminated soil within the bioventing zone of influence has likely been remediated to the extent that the residual contaminant mass is no longer sufficient to support measureable aerobic bacterial activity.

Groundwater data collected throughout the IM operation period indicate that after six quarters of operation, bioventing and EAD remedial mechanisms operated as planned to decrease the contaminant mass by increasing the rate of contaminant destruction in OA 9 vadose zone soil and groundwater. Heterogeneity of subsurface air flow pathways and contaminant source areas increases the variability of respirometry and performance monitoring data, making definitive spatial data evaluation more challenging.

Operation of the OA 9 IM was terminated in June 2010 in preparation for the Building 2-44 and Building 2-49 demolition. Remaining contamination surrounding subsurface utilities in the area will be excavated and removed as part of demolition of those utilities. Soil screening and sampling will be conducted and remaining petroleum-impacted soil with contaminant concentrations greater than cleanup levels will be excavated and appropriately disposed of as part of demolition work.

1.7 2-10 Area North and South Sheetpile SVE and ERD IMs

As summarized in *Technical Memorandum: Building 2-10: Areas of Concern 2-10.3A and 2-10.4A Summary of Interim Measures and Current Site Conditions* (Calibre 2017) Boeing began plans to implement IMs for areas of impacted soil and groundwater associated with the north and south sheetpiles in the 2-10 Building in 2008/2009. A significant amount of prior characterization data were available for the two areas; however, much of the groundwater data were more than 7 years old and not appropriate for design of the planned IMs. A Work Plan prepared in 2009 (Phase 1: Data Collection) defined the objectives and procedures for additional data collection deemed necessary for technology selection, design, and implementation of the IMs. A second Work Plan (Phase 2: IM Design and Implementation) was submitted for implementation after the remedial technologies for the IMs were selected; that plan summarized and evaluated the data collected under the initial Work Plan and proposed IMs for the 2-10 North and South Sheetpile areas.

Two remedial technologies, SVE and ERD, were identified as appropriate remedies for one or both sheetpile IMs; SVE for treating cVOCs in vadose zone soils; and ERD for treating cVOCs in groundwater and saturated soils. Both technologies have been implemented successfully at other areas of Plant 2 with similar geochemical conditions. SVE and ERD were considered the most likely IM technologies and the data collected during Phase 1: Data Collection were used to confirm the site-specific applicability of remedy selection for the IMs.

1.7.1 SVE System Status

By mid-2014 the 2-10 North and South Sheetpile SVE systems operated for approximately 16 months. Performance monitoring data from the SVE systems demonstrated significant declines in VOC vapors (99.9 percent reductions in the North Sheetpile and 99+ percent in the South Sheetpile). These contaminant reduction percentages are based on measurement of soil vapor concentration and inlet concentrations to the SVE systems). Based on the performance data, the 2-10 North and South Sheetpile SVE systems were recommended for shutdown and rebound testing. EPA subsequently approved the initial SVE system shutdown and start of rebound testing.

The document titled *Technical Memorandum: Remedial Optimization of 2-10 Interim Measures Sites: SVE Rebound and Groundwater Monitoring Summary* (Calibre and Floyd/Snider 2014) contains results of rebound testing of the SVE systems. The SVE operations and rebound test data indicated that soil vapor levels had been significantly reduced (99+ percent). These performance data, coupled with prior indoor air sampling data, demonstrated that soil vapor concentrations would not rebound to levels that could cause indoor air levels that exceed indoor air TMCLs/final media cleanup levels (FMCLs). In addition, the groundwater treatment processes in place have demonstrated any potential vapor transfer of COCs to groundwater would be effectively managed demonstrating that the SVE operations (for soil treatment) had fully met the IM objectives.

SVE and ERD combined had eliminated the potential indoor air exposure risk. It was recommended; therefore, that both SVE systems be decommissioned and that ERD, in both locations, be continued until cleanup goals are met in groundwater. EPA approved the SVE system shutdown and both systems were decommissioned (Calibre 2017).

1.7.2 ERD Status

Groundwater monitoring results for the 2-10 North Sheetpile area indicate that current monitoring results for TCE were non-detect at five of the seven wells sampled within the 2-10 North Sheetpile area. Well PL2-212A (adjacent to the former TCE degreaser pit) showed TCE at 26 µg/L, down from historical levels of 420,000 µg/L. To date, analytical data for samples from this well have demonstrated a 99.99+% reduction in TCE and a 99.6% reduction in total cVOCs from historical levels. The data collected from the remaining six wells inside the sheetpile area show similar reductions in cVOCs with concentrations continuing to decline or remain at non-detect. Wells PL2-258A and PL2-258B, down gradient and outside of the north sheetpile, show low levels of cVOCs (0.3 µg/L and 1.5 µg/L respectively) and continue to remain at or near non-detect after the initiation of ERD treatment (Calibre 2017).

Groundwater monitoring results for the 2-10 South Sheetpile area show a consistent trend of low level cVOCs or concentrations remaining at non-detect, as has been observed in previous sampling events. Well PL2-257A shows the highest total cVOC concentrations for this area, at 20.8 µg/L. A bio-augmentation injection was completed at this well along with IW-S-12 in March 2015 to promote accelerated degradation of the remaining VOCs. Wells PL2-214A and PL2-216A, located downgradient and outside of the 2-10 South Sheetpile, were sampled in November 2016 and results show all cVOCs at non-detect, consistent with historical data. Based on current groundwater data the remaining plume mass is centered at well PL2-257A which is located outside (up gradient) from the 2-10 South Sheetpile area. Groundwater treatment has continued in this area (i.e. at IW-S-12 adjacent to PL2-257A) with the most recent substrate injection event completed in August 2016. The site-wide sampling data will be reviewed and used to adjust and optimize the treatment plan (e.g., if specific areas have achieved the cleanup goals they may be dropped from further treatment).

The ongoing IMs have significantly reduced cVOC concentrations in soil and groundwater inside of the 2-10 North and South Sheetpiles. Groundwater monitoring data associated with these IMs are updated quarterly and data from the most recent available round of monitoring will be used as part of the remedial technology evaluation process described in Section 6 of the Corrective Measures Study (CMS) Volume X report. In addition, the most recent available data set up to December 2016 for the 2-10 Area North and South Sheetpile IMs are included in Attachment S4B of CMS Volume X.

1.8 Well Decommissioning

Boeing began extensive property modifications in early 2010 by demolishing existing infrastructure and constructing new utilities, parking, and stormwater features in the central and southern portions of Plant 2. At approximately the same time, the King County South Park Bridge replacement project affected some Boeing monitoring wells. In September 2012 Boeing began habitat restoration work in the North Area and filling and grading of Lot 16, which is located immediately west of the 2-10 Area. Many wells were either decommissioned or protected in advance of these construction projects.

The well decommissioning schedule presented in the well decommissioning IM Work Plan (EPI 2010b) was designed to be implemented in phases to allow important wells, such as shoreline monitoring wells and Electrical Manufacturing Facility (EMF) plume wells, to remain active for as long as reasonably possible to provide groundwater samples for their respective ongoing monitoring programs. In some cases, the decommissioning schedule was modified, with EPA's approval, to respond to changes in the demolition schedule.

Some wells originally classified as "wells to be protected" were later determined to be too close to demolition work to be effectively protected during the demolition work. In those cases Boeing informed EPA of the issue and obtained prior approval for well decommissioning. This approach ensured protection of groundwater, which can be put at risk if the wellheads or well seals are damaged during demolition and construction work.

In other cases, wells that were not anticipated to be damaged by demolition and construction work based on their distance from the actual subsurface work were inadvertently damaged beyond repair by equipment operation and required decommissioning to protect groundwater. In those cases, Boeing contacted EPA to inform the Agency of the need to decommission the damaged well.

Wells were decommissioned by a Washington State licensed driller in accordance with WAC 173-160-460 "Decommissioning Process for Resource Protection Wells." An Environmental Partners, Inc. (EPI) geologist or professional engineer licensed by the State of Washington supervised the drillers and documented the well decommissioning process for each well decommissioning event.

Prior to decommissioning, a hydrogeologist reviewed the well construction logs for the wells to be decommissioned to determine if the wells were constructed according to WAC 173-160-420 "General Construction Requirements for Resource Protection Wells". In addition, the well construction logs were provided to the drilling contractor for their review and to initiate preparation of well decommissioning permits as required by Ecology. Wells constructed according to WAC 173-160-420 specifications were decommissioned following the procedures specified in WAC 173-160-460(2).

Shallow, A-Level, monitoring wells were decommissioned by pouring bentonite chips into the well casing to approximately one-foot below ground surface (bgs) then hydrating the bentonite chips with potable water. Wells deeper than 30 ft. bgs (B- and C-Level wells) were decommissioned by grouting from the bottom to the top of the well with high-solids bentonite grout. Well drillers used a tremie pipe to ensure that grout filled the well from bottom to top of the well screen and casing. In all cases where wells were grouted, groundwater displaced by grout emplacement was captured and retained in 55-gallon drums for characterization and disposal.

The final step of well decommissioning was to remove the steel protective cover from the flush completion monument, fill the monument with concrete, and finish the concrete seal flush with the surrounding pavement surface.

A total of 173 monitoring wells were decommissioned as part of the Well Decommissioning Interim Measure Work Plan (EPI 2010b). Of the 173 wells decommissioned, 99 were completed in the A-Level, 58 in the B-Level, and 16 in the C-Level of the aquifer as summarized in the Well Decommissioning Summary Report (EPI 2013).

2.0 GROUNDWATER INTERIM MEASURES ASSOCIATED WITH REDEVELOPMENT

As part of Plant 2 redevelopment work performed in 2012 Boeing performed two site redevelopment IMs that were intended primarily to address impacted soil but contained components intended to benefit groundwater quality. These IMs are described in greater detail in Addendum #3 to the Interim Measure Work Plan – 2010/2011 Soil and Stormwater Management Plan, Demolition and Redevelopment activities, 2-40s and 2-31 Buildings and 2-60s/2-66 Area Slabs (Golder 2011). The two IMs associated with redevelopment are identified in Addendum #3 as “2-66 Sheetpile Containment Structure” and “Western Portion of Building 2 31” in Addendum #3. The locations of these two IM redevelopment actions are shown in Figure 3-5 in Volume X, Section 3. The two redevelopment groundwater IMs are described in the following paragraphs.

2.1 2-66 Sheetpile Containment Structure

The bulk of the sheetpile containment structure will be left intact for the foreseeable future to contain residual concentrations of contaminants in soil and groundwater and potentially accommodate additional groundwater remediation. The remediation of the soil in the sheetpile structure was substantially, though not fully, completed by the DDC IM. However, excavation of soil just outside the sheetpile in the adjacent Stormwater Area excavation or, in the future, in the vicinity may result in excessive loading on the sheetpile, affecting the stability of the sheetpile and the integrity of the seal (barrier) provided by the sheetpile. As such, the soil inside the sheetpile containment area was excavated simultaneously with the excavations around the perimeter of the containment area proposed in Addendum #3.

With the USEPA’s prior approval, Boeing added the commercially available remediation substrate product 3D Microemulsion™ by Regenesis™ to the bottom of the excavation at the groundwater surface and mixed the substrate into the soil prior to backfilling. The addition of remediation substrate was performed during the redevelopment excavation to continue the favorable reductive geochemical conditions initiated by the previous ERD IM and to enhance bacterial populations in anticipation of comprehensive remedies to be performed as part of corrective measures implementation.

2.2 Western Portion of Building 2-31

Groundwater COC maps contained in the 2-31 Area DGI report (EPI and Golder 2010) and the location of the historical TCE supply line were used to delineate the likely extents of the large excavation performed in the west portion of Building 2-31 (Figure 3-5). The excavation was intended to remove soil that was identified as a potential ongoing source of cVOC impacts to the groundwater in the 2-31 Area. The excavation was extended in some areas to groundwater at a depth of approximately 11 feet bgs. During excavation soil was visually observed for signs of staining, and a PID was used to monitor the soil for VOCs as needed.

With the USEPA’s prior approval, Boeing added 3D Microemulsion™ to the bottom of the excavation at the groundwater surface and mixed the substrate into the soil prior to backfilling. The addition of remediation substrate was performed during the redevelopment excavation to achieve favorable reductive geochemical conditions and enhance bacterial populations in anticipation of comprehensive remedies to be performed as part of corrective measures implementation.

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